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EMBRYONIC MORTALITY AND ABNORMALITIES OF AQUATIC BIRDS: APPARENT IMPACTS OF SELENIUM FROM IRRIGATION DRAINWATER

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ABSTRACT

Severe reproductive impacts were found in aquatic birds nesting on irrigation drainwater ponds in the San Joaquin Valley of California. Of 347 nests studied to late incubation or to hatching, 40.6% had at least one dead embryo and 19.6% had at least one embryo or chick with an obvious external anomaly. The deformities were often multiple and included missing or abnormal eyes, beaks, wings, legs and feet. Brain, heart, liver and skeletal anomalies were also present. Mean selenium concentrations in plants, invertebrates, and fish from the ponds were 22—175 ppm (dry weight), about 12 to 130 times those found at a nearby control area. Bird eggs (2.2—110 ppm) and livers (19—130 ppm) also contained elevated levels of selenium. Aquatic birds may experience similar problems in other areas where selenium occurs at elevated levels.

INTRODUCTION

The historic loss of nearly 95% of California's wetland habitat coupled with the scarcity and high cost of water have created interest among resource managers in using water from subsurface agricultural drains for the creation and management of wetlands (Gilmer et al., 1982). In the San Joaquin Valley, agricultural drainage water is already being used for marsh management at the Kesterson National Wildlife Refuge in Merced County. However, the effects of such water on plant and animal communities are unknown. Preliminary samples of mosquitofish (*Gambusia affinis*) collected in 1982 from Kesterson Reservoir, a series of 12 shallow drainwater evaporation ponds totalling about 500 ha on the Kesterson Refuge, contained selenium concentrations nearly 100 times those in samples from the nearby (10 km away) Volta Wildlife Area which does not receive drain water.

Selenium is toxic to livestock, poultry, and perhaps fish under environmental conditions found in certain regions (Fishbein, 1977; Wilber, 1980; Sorensen et al., 1984). However, adverse effects of selenium have not been reported in wild birds. Our objective was to determine whether selenium or other contaminants were present in the evaporation ponds at Kesterson at concentrations harmful to aquatic birds.

Following our discovery of adverse effects on bird reproduction, the U.S. Geological Survey (USGS) conducted studies to determine the source of the selenium. The implications of these findings affect large areas of agricultural land in the San Joaquin Valley; they may also apply to other areas where selenium occurs at elevated levels in soils or water. Such areas occur elsewhere in the United States as well as in Canada, Mexico, Colombia, Ireland, Israel, South Africa and Australia (Rosenfeld and Beath, 1964).

MATERIAL AND METHODS

We studied the reproductive success of aquatic birds at Kesterson and Volta between April and July 1983. Several species were included in the study, including American coot (*Fulica americana*), mallard (*Anas platyrhynchos*), northern pintail (*A. acuta*), cinnamon teal (*A. cyanoptera*), gadwall (*A. strepera*), black-necked stilt (*Himantopus mexicanus*), American avocet (*Recurvirostra americana*) and eared grebe (*Podiceps nigricollis*). Nests were marked and checked weekly during the incubation periods. Eggs collected during incubation or eggs that failed to hatch were examined to determine the condition of the embryo; some eggs were then analyzed for selenium and seven heavy metals (Ag, As, Cd, Cr, Hg, Pb and Zn). Chicks in nests were checked for abnormalities. Adult birds were collected to determine qualitatively their diets and to provide tissues for selenium and metal analysis. Water and food chain organisms were collected during May 1983 so as to measure contaminants.

All samples were analyzed for selenium by hydride generation—atomic absorption spectroscopy (H—AA) at the Environmental Trace Substances Research Center (ETSRC), Columbia Missouri (Whetter and Ullrey, 1978; USEPA, 1983). Within-laboratory accuracy and precision of the analyses were determined through the use of standard reference materials, spiked samples, and replicated sample aliquots. Fourteen samples were analyzed twice at ETSRC; the average percent difference in values for selenium in these duplicate analyses was 13.9%. (For those and the several other samples that were analyzed more than twice, we used the mean of all values obtained from that laboratory.)

Inter-laboratory cross-check analyses of 10 samples were conducted by H—AA at the Columbia National Fisheries Research Laboratory (May, 1982; USEPA, 1983). The average percent difference in selenium concentration values was 14.7%. To confirm the H—AA values, non-destructive instrumental neutron activation analysis (INAA) was conducted on split-sample aliquots covering five different sample matrices (plankton, Anisoptera, mosquitofish, etc.) at the University of Missouri Research Reactor (McKown and Morris, 1978). The average difference between INAA and H—AA for selenium in these samples was 8.6%.

The ETSRC also analyzed several of the samples of rooted plants, insects, mosquitofish and bird livers and eggs for arsenic by H—AA (Perkin—Elmer, 1979), boron by inductively-coupled plasma emission spectroscopy (Boumans and deBoer, 1972, 1975; Greenfield et al., 1975), cadmium, chromium, copper, lead, molybdenum, nickel and silver by graphite furnace-atomic absorption spectroscopy (Fernandez and Iannorone, 1978; Perkin—Elmer, 1980; Hinderberger et al., 1981; Kaiser et al., 1981), mercury by cold vapor-atomic absorption spectroscopy (Koirtyohann and Khalil, 1976) and zinc by flame-atomic absorption spectroscopy (Perkin—Elmer, 1982). Standard reference materials, spiked samples, and replicated sample aliquots were used to determine within-laboratory accuracy and precision of the analyses, which were similar to those for selenium.

Primary emphasis in the present paper is on bird reproduction and selenium concentration in the food chain. However, a few bird livers and eggs were analyzed to determine the general level of contaminant accumulation in bird tissues. Additional liver and egg samples have been analyzed at another laboratory to enable (1) detailed species comparisons, and (2) the relationship between selenium concentration in a sample egg and the probability of success of eggs remaining in the nest. Those results will be published separately (H.M. Ohlendorf et al., in preparation).

RESULTS AND DISCUSSION

Bird reproduction

Embryonic mortality was high at Kesterson with coot and grebe eggs having the highest rate (Table 1). Other published studies show that coots lose relatively few eggs (0.1—1.7% of eggs laid) to embryonic death (Miller and Collins, 1954; Hunt and Naylor, 1955; Kiel, 1955; Gorenzel et al., 1982). Coots nesting at Kesterson lost 14.6% of their eggs to embryonic mortality, or about nine times more than expected.

TABLE 1
FREQUENCY OF EMBRYONIC MORTALITY AND ABNORMALITIES IN EMBRYOS AND YOUNG OF AQUATIC BIRDS USING KESTERSON RESERVOIR, 1983

Species	Total	Dead embryos		Abnormal embryos or chicks	
		N	%	*N*	%
Coot					
Nests	59	35	59.3	25	42.4
Eggs	487	71	14.6	43	8.8
Ducks					
Nests	30	5	16.7	3	10.0
Eggs	277	7	2.5	11	4.0
Stilt					
Nests	102	17	16.7	18	17.6
Eggs	397	23	5.8	27	6.8
Grebe					
Nests	140	84	60.0	22	15.7
Eggs	457	145	31.7	25	5.5
All species					
Nests	347[a]	141	40.6	68	19.6
Eggs	1681[a]	246	14.6	106	6.3

[a] Totals include 16 avocet nests with 63 eggs in which no abnormalities or mortality occurred.

Circumstantial evidence suggests that mortality of hatchlings was also high at Kesterson. Although at least 258 coot eggs and 211 grebe eggs presumably hatched in our Kesterson study area, we saw less than 10 young coots and only one young grebe. Young coots and grebes leave the nest soon after hatching but are flightless and dependent on the adults for food and protection for several weeks. Consequently, we should have seen young associated with adults after hatching, as observed in other studies (e.g. Gullion, 1954; Ryder, 1961; Gould, 1974); we saw young coots and grebes at Volta, although fewer nested there than at Kesterson. Some young with severe externally visible deformities did hatch, but their abnormalities must have prevented survival beyond a few days. Less obvious internal deformities also probably prevented survival of many young.

Severe developmental abnormalities occurred in embryos and hatchlings from four groups of aquatic birds at Kesterson (Tables 1 and 2, Fig. 1). Multiple malformations were often present and included defects of the eyes (anophthalmia and microphthalmia), legs and wings (micromelia and amelia), feet (ectrodactyly and clubfoot), beak (missing, reduced, or crossed), and brain (hydrocephaly and exencephaly). In addition, internal defects of the heart (thin ventricular walls and swelling), liver (size variation), and skeleton (multiple defects) also occurred in some embryos.


Fig. 1. Abnormal embryos from eggs of aquatic birds at Kesterson. *Left:* American coot with truncated feet; this embryo also had poorly developed eyes and no lower beak. *Right:* Black-necked stilt with abnormal lower beak and poorly developed eyes; both legs and one wing were absent.

Defects of the eyes, legs and wings were almost always bilateral. Abnormalities of the beak were usually in the lower mandible. The incidence of leg/foot abnormalities in grebes was probably higher than shown in our counts. Many of the grebe embryos had begun decomposing and we were not able to examine them in as much detail as those of other species.

Overall, 19.6% of 347 nests followed through the late stages of incubation or hatching had at least one embryo or chick with an overt anomaly; of all eggs in these nests 6.3% contained abnormal embryos (Table 1). The expected incidence of major external malformations in hatchlings of uncontaminated wild populations of birds and in embryos of laboratory-incubated mallard

TABLE 2

FREQUENCY OF VARIOUS TYPES OF ABNORMALITIES IN EMBRYOS AND CHICKS OF AQUATIC BIRDS AT KESTERSON RESERVOIR, 1983

Species	N[a]	Abnormalities[b]					
		Eyes	Legs/feet	Beak	Hydrocephaly	Exencephaly	Wings
Coot[c]	59	22	20	3	7		
	(487)	(32)	(25)	(4)	(11)		
Ducks	30	3	3	3	1		
	(277)	(5)	(9)	(8)	(1)		
Stilt[d]	102	17	9	11	4	2	4
	(397)	(26)	(14)	(15)	(7)	(2)	(5)
Grebe[e]	140	19	4	4	2	3	
	(457)	(21)	(4)	(4)	(2)	(3)	

[a] Number of nests and (eggs) followed through late stages of incubation or hatching.
[b] Number of nests and (eggs) in which an embryo or chick had the abnormalities listed (see text for further description).
[c] Gastroschisis in one coot embryo.
[d] Gastroschisis in one stilt embryo; encephalocele in another.
[e] Encephalocele in one grebe embryo.

TABLE 3
SELENIUM CONCENTRATION (ppm, dry weight) IN BIRD LIVERS AND EGGS, 1983[a]

Species	Volta			Kesterson					
	Livers			Livers			Eggs		
	N	Mean[b]	(Range)	*N*	Mean	(Range)	*N*	Mean	(Range)
Coot	3	5.01	(4.4—5.6)	3	37.2	(21—63)	5	54.0	(34—110)
Ducks	2	4.14	(3.9—4.4)	2	28.6	(19—43)	4	9.90	(2.2—46)
Stilt	1	6.1					5	32.7	(12—74)
Avocet[c]							1	9.1	
Grebe				1	130		5	81.4	(72—110)

[a] All samples analyzed contained measurable concentrations.
[b] Geometric means.
[c] One egg collected at Volta contained 2.7 ppm selenium (dry weight).

eggs is less than 1% (Pomeroy, 1962; Gilbertson et al., 1976; Hoffman, 1978; Hill and Hoffman, 1984). We found no abnormalities in embryos from the Volta Wildlife Area in 1983 or in two subsequent years. During this period we followed 92 nests there through the late stages of incubation or hatching.

Selenium in birds and their foods

Average selenium concentrations in livers of adult birds were about seven times greater at Kesterson than mean concentrations found at Volta (Table 3). In areas without selenium contamination, dry-weight concentrations are usually less than 3 or 4 ppm in bird eggs and 12—16 ppm in livers (Blus et al., 1977; Haseltine et al., 1981; King et al., 1983). At Kesterson the mean selenium concentrations in eggs and livers ranged from several to 20 times those levels (Table 3). Similar differences have been found in other samples of aquatic bird livers and eggs analyzed from these two areas (H.M. Ohlendorf et al., in preparation).

Selenium concentrations were greater than 40 ppm in 11 of 15 coot, stilt and grebe eggs analyzed. Each of these eggs came from a nest with reproductive problems; in some of those nests, all eggs failed to hatch. Those eggs with lower concentrations were from nests where some eggs hatched.

We collected and analyzed food organisms like those consumed by birds shot during our study. Average selenium concentrations in food items at Kesterson were about 12 to 130 times greater than in samples from Volta (Table 4). The concentration of selenium in mosquitofish from Volta is near the mean concentration (0.56 ppm wet weight, or about 2.0 ppm dry weight) found in fish throughout the United States in the National Pesticide Monitoring Program during 1976—77 (May and McKinney, 1981).

TABLE 4
SELENIUM CONCENTRATION (ppm, dry weight) IN COMPOSITE SAMPLES OF PLANTS, INVERTEBRATES, AND MOSQUITOFISH, MAY 1983

Sample	Volta			Kesterson		
	N[a]	Mean[b]	(Range)	*N*	Mean	(Range)
Filamentous algae	0/4	ND[c]		6/6	35.2	(12—68)
Rooted plants	1/1	0.43		18/18	52.1	(18—79)
Net plankton	4/4	2.03	(1.4—2.9)	7/7	85.4	(58—124)
Water boatmen (Corixidae)	5/5	1.91	(1.1—2.5)	2/2	22.1	(20—24)
Midge larvae (Chironomidae)	3/3	2.09	(1.5—3.0)	3/3	139	(71—200)
Dragonfly nymphs (Anisoptera)	2/2	1.29	(1.2—1.4)	6/6	122	(66—179)
Damselfly nymphs (Zygoptera)	2/2	1.45	(1.2—1.7)	3/3	175	(118—218)
Mosquitofish (*Gambusia affinis*)	5/5	1.29	(1.2—1.4)	12/12	170	(115—283)

[a] Number with measurable concentrations/number analyzed.
[b] Geometric means; computed only when selenium was measurable in at least 50% of samples. When only one sample was analyzed the concentration is shown in this column.
[c] ND = not detected.

Grebes and stilts contained only aquatic insects, whereas ducks and coots supplemented their herbivorous diets with insects. These observations are consistent with other studies (Palmer, 1962, 1976; Bellrose, 1976; Cogswell, 1977).

Location of feeding sites also varied among the bird species. Grebes and coots were rarely seen flying and those nesting at Kesterson probably fed exclusively in the ponds. Many ducks and some stilts were seen leaving or returning to the Kesterson ponds; thus they may have fed in less polluted environments nearby. Coots are the most resident of the species studied, whereas ducks, stilts, avocets, and grebes are migratory to varying degrees. We believe these differences in dietary habits, local feeding sites and migratory patterns result in different exposures to selenium, and these differences, in turn, are important in determining mortality and deformity rates.

Our study indicates that the reproductive success of aquatic birds using the ponds at Kesterson was dramatically reduced by both poor hatching success and low survival of young; the evidence implicates selenium as the causative agent. The external deformities were similar to those in embryos of chickens and mallards fed diets containing 7—25 ppm of selenium (Poley et al., 1937; Ort and Latshaw, 1978; G.H. Heinz and D.J. Hoffman, Patuxent Wildlife Research Center, Laurel, Maryland, personal communication, 1985), or when selenium compounds were injected into eggs (e.g. Palmer et al., 1973). Additionally, selenium reduced the hatching success, growth, or

TABLE 5
HEAVY METAL CONCENTRATIONS (ppm, dry weight) IN BIRD LIVERS AND EGGS, 1983

Metal	Volta[a]			Kesterson[a]					
	Livers			Livers			Eggs		
	N[b]	Mean[c]	(Range)	N	Mean	(Range)	N	Mean	(Range)
Ag[d]	2/2	0.201	(0.15—0.27)	4/4	1.02	(0.61—1.8)	0/4	ND[e]	
As[f]	3/6	0.251	(ND—0.89)	1/6		(ND—0.79)	3/20		(ND—2.9)
Cd[d]	2/2	0.583	(0.34—1.0)	4/4	0.362	(0.12—0.96)	0/4	ND	
Hg[f]	6/6	1.04	(0.48—2.2)	6/6	1.05	(0.35—10)	20/20	0.72	(0.08—4.3)
Pb[d]	2/2	0.255	(0.21—0.31)	1/4		(ND—3.2)	0/4	ND	
Zn[d]	2/2	120.	(110—130)	4/4	105	(55—170)	4/4	47.8	(32—84)

[a] One avocet egg from Volta contained $<$ 0.2 ppm As and 0.49 ppm Hg. Cr was below the detection limit (0.4 ppm, dry weight) in two coot livers from Volta, one mallard and three coot livers from Kesterson, and in three coot eggs from Kesterson; present at 2.7 ppm in one coot egg from Kesterson.
[b] Number with measurable concentrations/number analyzed.
[c] Geometric means; computed only when a particular metal was measurable in at least 50% of samples.
[d] Analyzed in coot livers from Volta and in one mallard liver, three coot livers, and four coot eggs from Kesterson.
[e] ND indicates element was not found above the limits of detection (0.04 ppm for Ag and Cd; 0.2 ppm for As and Pb).
[f] Analyzed in all liver and egg samples (see Table 3 for species composition).

survival of young in poultry, quail, and mallards (Arnold et al., 1973; Hill, 1974; El-Begearmi et al., 1977; Ort and Latshaw, 1978; G.H. Heinz, personal communication, 1985). Analyses of bird tissues, eggs and food chain organisms from Kesterson indicate that our study birds ate a diet high in selenium and incorporated selenium into their tissues at levels greater than those known to cause reproductive problems in poultry. At Volta, selenium concentrations in tissues and foods of birds were low, and no deformities were found.

Source and chemical form of selenium

Selenium enters Kesterson Reservoir from the San Luis Drain, a U.S. Bureau of Reclamation canal that transports subsurface drainwater from western Fresno County. We found concentrations of dissolved selenium in the Drain at Kesterson during May 1983 that approximated 300 ppb; this value is near the concentration found by U.S. Geological Survey (USGS) investigators at that location in August and November 1983 (Presser and Barnes, 1984). The San Joaquin Valley is not generally recognized as an area with high natural levels of selenium, but samples of shale and vegetation from the Coast Range have moderate concentrations (Lakin and Byers, 1941; Kubota et al., 1967).

Preliminary findings suggest that the selenium originated from shale formations in the Coast Range along the western side of the San Joaquin Valley (Deverel et al., 1984). Irrigation leaches soluble forms of selenium and transports them through the soil. However, the extent of the area containing significant levels of selenium remains unknown.

Selenium occurs primarily in the form of selenate(s) in the alkaline water of Kesterson Reservoir (Deverel et al., 1984; Presser and Barnes, 1984). Biota from Kesterson have not yet been analyzed to determine the chemical forms of selenium present. However, it is thought that most of the selenium in plants, invertebrates, and fish is in organic forms such as selenomethionine or selenocystine, for these are commonly found in proteins (Ganther, 1974). Selenomethionine is more readily transferred to eggs than inorganic forms such as sodium selenite (Latshaw and Osman, 1975; G.H. Heinz, Patuxent Wildlife Research Center, Laurel, Maryland, personal communication, 1985).

Metals and other contaminants

Heavy metal concentrations were generally similar in bird livers (Table 5) and in food organisms (Table 6) from the two areas. These metals are therefore considered unlikely to have caused the embryonic mortality and abnormalities we observed.

Boron occurred at high concentrations in plants, insects, and fish at Kesterson (Table 6). Little is known about the effects of boron ingestion on the reproduction of birds. However, boron compounds (e.g. boric acid and borax) produce mortality and teratogenic development when they are injected into the egg (Landauer, 1952; Birge and Black, 1977). For this reason, further study is warranted to determine whether ingested boron may be transmitted to the egg and adversely affect the hatchability and development of embryos.

Organochlorine concentrations in mosquitofish from Kesterson were low. Polychlorinated biphenyl (PCB 1248; up to 60 ppb) and p, p'-DDE (22—44 ppb) concentrations were measurable, but 21 other organochlorine compounds were not found above the limits of detection (10—50 ppb). Therefore, we believe that organochlorines are not responsible for the observed effects on reproduction.

General

Because selenium is an essential trace element in many animals, it is assumed to be essential in man. Although dietary requirements are not well defined, the recognized safe and adequate daily intake is in the range 50—200 μg day^{-1} (Shamberger, 1981; Levander, 1983). Based on the incidence of selenosis found in people from the seleniferous areas of South Dakota (Kilness and Hochberg, 1977), and considering the normal levels in

TABLE 6

CONCENTRATIONS (ppm, dry weight) OF TRACE ELEMENTS EXCLUDING SELENIUM IN COMPOSITE SAMPLES OF ROOTED PLANTS, AQUATIC INSECTS, AND MOSQUITOFISH, MAY 1983

Element	Volta								
	Plants			Insects			Mosquitofish		
	N[a]	Mean[b]		N	Mean	(Range)	N	Mean	(Range)
Ag	0/1			5/5	0.152	(0.07—0.22)	2/2	0.040	(0.04)
As	1/1	5.4		10/10	1.26	(0.66—5.9)	2/2	0.426	(0.42—0.43)
B	1/1	34		5/5	13.4	(6.2—35)	1/2	2.75	(ND—3.6)
Cd	0/1			4/5	0.189	(ND—0.65)	0/2	ND	
Cr	1/1	31		5/5	3.03	(1.1—7.1)	2/2	0.389	(0.36—0.42)
Cu	1/1	14		5/5	20.4	(12—45)	2/2	3.58	(3.4—3.8)
Hg	0/1			8/9	0.259	(ND—0.46)	2/2	0.330	(0.29—0.38)
Mo	0/1			2/5		(ND—1.6)	0/2	ND	
Ni	1/1	36		4/5	2.12	(ND—6.1)	2/2	1.09	(0.93—1.3)
Pb	1/1	4.5		5/5	0.610	(0.33—1.1)	0/2	ND	
Zn	1/1	17		5/5	108	(71—210)	2/2	126	(120—130)
Element	**Kesterson**								
	Plants			Insects			Mosquitofish		
	N	Mean	(Range)	N	Mean	(Range)	N	Mean	(Range)
Ag	0/9	ND		6/7	0.093	(ND—0.28)	4/4	0.122	(0.04—0.32)
As	18/18	1.80	(0.84—3.4)	12/13	0.880	(ND[c]—2.9)	4/4	0.664	(0.47—0.88)

B	9/9	382.	(270—510)	7/7	45.2	(36—54)	4/4	11.1	(8.0—20)
Cd	0/9	ND		7/7	0.117	(0.06—0.22)	2/4	0.041	(ND—0.09)
Cr	3/9		(ND—2.0)	3/7		(ND—1.0)	0/4	ND	
Cu	9/9	5.55	(3.9—7.4)	7/7	19.2	(12—46)	4/4	6.76	(5.2—8.4)
Hg	0/18	ND		4/14		(ND—0.34)	2/4	0.068	(ND—0.16)
Mo	9/9	5.25	(3.6—6.8)	6/7	0.772	(ND—2.1)	0/4	ND	
Ni	9/9	3.05	(1.9—4.6)	5/7	0.661	(ND—2.1)	4/4	1.05	(0.96—1.2)
Pb	3/9		(ND—0.83)	4/7	0.207	(ND—0.37)	0/4	ND	
Zn	9/9	22.4	(10—51)	7/7	89.3	(67—190)	4/4	155	(140—160)

[a] Number with measurable concentrations/number analyzed.
[b] Geometric means; computed only when a particular trace element was measurable in at least 50% of samples. When only one sample was analyzed the concentration is shown in this column.
[c] ND = not detected.

foods, 500 μg day^{-1} is regarded as the maximum tolerable level (Sakurai and Tsuchiya, 1975; Lo and Sandi, 1980), whereas 1000 μg day^{-1} may produce chronic toxicity (Fishbein, 1977; L. Fishbein, National Center for Toxicological Research, personal communication, 1985) and 2400—3000 μg day^{-1} is considered a toxic chronic dose (Wilber, 1980). However, the toxicology of excess dietary selenium in humans is not clear (NRC, 1983).

Duck breast tissue collected at Kesterson during our study contained 1.0—9.5 ppm selenium (wet weight; $\bar{x}$ = 3.81 ppm; N = 18), much higher than at Volta (0.19—0.65 ppm; $\bar{x}$ = 0.442 ppm; N = 5). Selenium concentrations in coot breast muscle from a December 1983 collection by the California Department of Fish and Game at Kesterson Reservoir ranged from 1.3 to 11 ppm (wet weight; $\bar{x}$ = 3.21 ppm; N = 44) (D.A. Daniel, California Department of Fish and Game, Sacramento, personal communication, 1984). The consumption of 50 g of meat containing 10 ppm selenium would provide 500 μg of selenium. Due to findings in coots, the area was posted by state agencies advising that "The Department of Health Services recommends that adults not consume more than one meal per week of coots from this area, and that *no* coots from this area be eaten by children or pregnant women".

Selenium-related reproductive problems in aquatic birds have been observed only at Kesterson Reservoir; however, similar problems may now exist over a much wider area which could expand markedly in the future. In the San Joaquin Valley, there are more than 5300 ha of drainwater ponds like those at Kesterson (S.J. Green, California Central Valley Regional Water Quality Control Board, Fresno, personal communication, 1984), and nearly 28000 ha of evaporation ponds will be needed if subsurface drains are installed in all Valley fields requiring drainage (USBR, 1984).

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